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POST PILLAR RECOVERY STRATEGIES AT NANISIVIK MINE

PHASE 3 : PILLAR RECOVERY TRIAL

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and F. Bailey

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POST PILLAR RECOVERY STRATEGIES AT NANISIVIK MINE PHASE 3 : PILLAR RECOVERY TRIAL

by

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ABSTRACT

Under the Northwest Territories Mineral Development Agreement (NWT-MDA), CANMET was subcontracted by Nanisivik Mines Limited to carry out a technical study to define procedures and strategic mine planning for consideration in the complete extraction of post-pillars. The study by contributing to the safe, productive extension of the mine's life is expected to have a positive socio-economic impact on the Northwest Territories.

This report presents the results of a pillar recovery trial carried out in a test stope located in the extreme east end of the Main Ore Zone. The purpose was to verify the results of the stability assessments carried out as part of the Phase 2 study. Five pillars were successfully removed in the trial without incident. Observations and field instrumentation confirmed ground stability consistent with the earlier analytic assessments. The study has had a significant impact on the mine operators' confidence in looking at options with respect to mining the remaining post-pillars

Back analysis and monitoring data were used to validate the model and input parameters used. Field abutment and pillar stresses, determined using CANMET strain rings, were compared with those predicted by numerical model simulation. The results were in good agreement,

Planning is presently underway by Nanisivik Mines Ltd. to implement a full scale program of post-pillar recovery.

Key words : Post-pillar; Ground monitoring; Permafrost; Pillar mining; Modelling

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STRATÉGIES DE RÉCUPÉRATION DES STOTS À LA MINE NANISIVIK PHASE 3 : ESSAI DE RÉCUPÉRATION DES PILIERS

par

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RÉSUMÉ

En vertu de l'entente sur l'exploitation minérale conclue avec les Territoires du Nord-Ouest (TNO-EEM), Nanisivik Mines Ltd. a passé un sous-contrat avec CANMET en vertu duquel ce dernier effectuera une étude technique en vue de définir des procédures et une méthode stratégique de planification minière pour faciliter l'extraction complète des stots. En contribuant à l'extraction sécuritaire du minerai et en prolongeant la durée d'exploitation de la mine, l'étude devrait avoir un impact socio-économique positif dans les territoires du Nord-Ouest.

Les résultats de l'essai de récupération des piliers mené sur un chantier d'essai situé à la limite extrême Est du gisement principal sont présentés dans ce rapport. L'essai a été mené en vue de vérifier les résultats des évaluations de la stabilité du terrain effectuées dans la Phase 2 de l'étude. Au cours de l'essai, on a réussi à extraire cinq piliers sans problème. Les observations et l'appareillage utilisé sur le terrain ont confirmé les données des analyses antérieures relatives à la stabilité du terrain. L'étude a eu un impact considérable sur l'atttude des exploitants de la mine qui ont maintenant des options quant au mode d'extraction des stots restants.

Une rétro-analyse et des données de monitorage ont été utilisées pour homologuer le modèle et les paramètres d'entrée utilisés. La poussée et les contraintes dans les piliers ont été déterminées au moyen des anneaux de déformation de CANMET et les données ont fait l'objet d'une comparaison avec celles obtenues par simulation à l'aide d'un modèle numérique. Les résultats concordaient.

Nanisivik Mines Ltd. a déjà entrepris la planification des opérations en vue de mettre en oeuvre un programme complet de récupération des stots.

Mots clés : stot; surveillance du terrain; pergélisol; récupération des piliers; modélisation

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1. INTRODUCTION

Under the Northwest Territories Mineral Development Agreement (NWT-MDA), Canada Centre for Mineral and Energy Technology (CANMET) was subcontracted by Nanisivik Mines Limited to carry out a technical study to define procedures and strategic mine planning for consideration in the complete extraction of post-pillars. The study by contributing to the safe productive extension of the mine's life, is expected to have a positive socio-economic impact on the Northwest Territories.

This is the final phase of a 3 phase study carried out for the above commission. In situ stress determinations and ground control instrumentation investigations were carried out in Phase 1 to establish rock mass characteristics and to provide relevant input data for computer simulations. In Phase 2 the overall ground stability of mine geometries with various pillar extraction options were assessed to develop guidelines for company use in mine planning and ground control.

Phase 3, a pillar removal trial, was carried out to physically confirm the applicability of the guidelines for post-pillar mining without backfill.

This report presents the results of the pillar removal trial. Five pillars were successfully removed in the trial as planned. The ground appears to be stable as predicted and this has been confirmed by subsequent instrumentation results and observations. The mine operators are taking the trial results into considering in planning the mining of the remaining pillars; a plan to complete post-pillar recovery will be implemented in the near future.

2. BACKGROUND

Nanisivik Mine, located at the north end of Baffin Island, (see Figure 1), is mainly producing zinc ore. The ore body consists of sphalerite and galena in a pyrite matrix and has dolomites of the Society Cliffs Formation as the host rock. The mine is entirely within the permafrost zone, which extends to a depth of 600 m below surface. The year round underground temperature in the mine is from -10^0 to -12^0 C. Room-and-pillar mining is employed at a production rate of about 2400 tonnes/day. The approximately 350 post-pillars which have been left in place to stabilize the back contain about 800,000 tonnes of ore grading 10.5% Zn, 0.7% Pb and 54 gm/tonne Ag. The ore represents about 15% of the original reserves of the deposit. Complete post-pillar recovery of these reserves would extend the mine life by more than a year, and would significantly contribute to the socio-economy of the Northwest Territories through employment.

Details of mine geology, mining operations, in situ stress determinations, ground control instrumentation and ground stability assessment are presented in Phases 1 and 2 Reports (1, 2). The principal findings of these studies are presented below:

2.1 Rock Mass Characteristics

Nanisivik Mine's rock mass characteristics were established from field and laboratory investigations which involved TV borehole inspections, dilatometer tests, ground stress determinations, ground movement monitoring and mechanical properties tests of the mine rocks (1). The following are the main conclusions:

1. The host rock is strong and massive. Inspection of roof strata up to 6.6 m above the roof line indicated sound roof conditions except for minor blast damage close to the roof line and some minor fracturing near the East portal.
2. Ground stress determinations in the dolomite of the south abutment established that the maximum stress, oriented NE-SW in the horizontal plane, has an average magnitude of 4.5 MPa. The maximum ratio of horizontal to vertical stress is 3.2:1. The magnitude of the vertical stress is due to overburden load.
3. The dolomite and sulphide behave elastically.

2.2 Ground Stability Assessment

The overall ground stability was assessed based on the results of finite element computer simulations and engineering judgement (2). The investigations included crown pillar stability, sill pillar stability, stope stability and the impact of pillar mining sequence. The following are the main conclusions from the simulations:

1. Ground failure should not be a significant factor. On the basis of rock mechanics and ground control considerations, the complete removal of post-pillars without backfill should be feasible.
2. The crown pillar is considered stable. Engineering equations are provided as a guide to achieve ground control and provide necessary ground support in its design.
3. The sill pillar between the main ore zone and the lower lens is considered to be stable. However, ground conditions and major discontinuities should be carefully observed, especially in the areas measured from the stope corner out to $\frac{1}{4}$ of the pillar span where high tensile stresses are developed and additional ground control measures might

be required. The synergistic effect of high tensile stresses and poor ground conditions or major discontinuities could cause sill pillar stability problems.

4. When the thickness of the north abutment is less than twice the stope width, the best pillar mining sequence is the following: mine the south side pillar first, then the north side pillar and the central pillar last. This sequence should minimize pillar loads and the extent of potential ground failure zones, especially in the eastern portion of the main ore zone.

5. When the thickness of an abutment is greater than twice the stope width, especially in the central portion of the main ore zone, the best pillar mining sequence is the following: mine the central pillar first followed by the north or south pillar. Due to symmetry the model does not indicate an order of preference.

6. From the point of view of access and ground control, post-pillar extraction should be started from the extreme east end of the main ore zone and retreat towards the west.

7. Careful blasting procedures should be used near the tops of the pillars to minimize roof damage and to maintain ground stability.

8. In the eastern portion of the main ore zone,the ground near the north abutment is more prone to failure than ground near the south abutment. In addition to the present ground monitoring systems, MRL rings should be installed in the north abutment to determine stress changes induced by mining during pillar extraction.

9. If poor ground conditions exist in high tensile stress zones, artificial ground reinforcement should be used to stabilize stope walls and to minimize dilution.

10. The geological structural features should be mapped as accurately as possible for use in establishing ground control and ground support requirements.

11. During pillar extraction, ground conditions should be regularly observed and the information fed back to CANMET for use in back analyses, development of a ground control expert system and, if necessary, additional simulations for use by Nanisivik in undertaking design modifications.

3. POST-PILLAR RECOVERY TRIAL

Based on the positive conclusions from the Phase 2 study as summarized in the above section, it was decided to proceed to Phase 3: a pillar recovery trial to verify the findings of Phase 2 and provide a degree of confidence in considering post-pillar mining. The following are actions taken with respect to the test stope trial:

3.1 Test Site Selection

Post-pillars in the eastern portion of the main ore zone between sections 19250E and 19350E were chosen for the test trial for the following reasons:

1. The site is located at the extreme east end of the main ore zone and will not interfere with regular production. Primary mining in this area was already complete.
2. The pillars are not too high to drill and blast, permitting the use of available equipment at the mine site.
3. This area has the most potential for ground problems because it has the thinnest crown pillar and is located near the portal where strata has the highest degree of fissuration. If the ground is stable after pillar removal in this area, removal of the rest of the pillars can be approached with additional confidence. If caving should occur, the remaining ore could still be mined by retreating westward with no significant impact on production.

Five pillars were selected for the recovery trial. Figure 2 shows pillar locations and the test site area. The site covers an area of about 8500 m^2 with an average width of 75 m. The pillars are spaced at a separation distance of about 20 m and have an average cross-section area of 64 m^2; average pillar height is 6.5 m. The crown pillar thickness varies from 28 m at the north to 48 m at the south wall.

3.2 Pillar Mining (3)

A total of 7400 tonnes of pillar ore was successfully mined from the test stope. Following are some detailed information on mining operation associated with pillar recovery:

3.2.1 Drilling

Two different hole sizes and patterns were dry drilled, using Jarvis Clark RBM-11 rock-bolting machine equipped with a NML dust collector. The first three pillars were

drilled with 63.5 mm holes on a 1.5×1.5 m pattern, while the last two pillars were drilled with 50.8 mm holes on a 1.2×1.2 m pattern. Extra back holes were drilled on 0.6 m to 0.7 m spacing and left uncharged when blasting to control roof damage. Fragmentation results were similar for both patterns. From a practical point of view, it seems that 63.5 mm holes on a 1.4× 1.4 m pattern would be the most cost effective. However, more work needs to be done to determine which drill pattern is most economical for drilling the remaining pillars.

3.2.2 Blasting

All blasting was done using ANFO with Nonels, B-Line and electrical detonators as accessories. To minimize back damage, back holes were traced with B-Line, primed by Nonel with Cilgel, or simply loaded with ANFO and traced with B-Line. Both methods produced similar results.

All five pillars were blasted using the same blasting sequence, i.e., the bottom three rows of holes were slashed out first, with succeeding rows blasted in succession with a single delay per row. The general results from the blasts were good. No significant oversized material was produced. The blasted stope backs are smooth. This blasting sequence seems to be the optimum to control fragmentation and to achieve reasonable muck distribution.

Figures 2 and 3 show the pillar extraction sequence and the area created by extraction of the five pillars, respectively. Below are data on the five pillar blasted in the trial.

No	Date	Pillar recovered	Tonnes (approx.)
1	04/02/1991	P38-10/1	1800
2	28/02/1991	P37-11/2	1100
3	06/03/1991	P37-11/1	1200
4	18/03/1991	P37-10/1	1600
5	27/04/1991	P37-10/2	1700
Total			7400

3.2.3 Fragmentation and Throw of Muck

Observation of the muck piles produced by blasting the five pillars indicated that fragmentation and throw of muck were very good. The majority of the muck size was less than 30 cm; no significant amount of oversized or flyrock was produced. The muck was generally piled around the pillars within a radius of 15 m.

3.2.4 Problems

The following factors were noted as impacting on blasting effectiveness: pillars not completely separate from the contact, loose on the side of a pillar or the drill holes not deep enough. In the case of P37-11/1 and P37-11/2 the dolomite left on the north side of the pillar peeled down with the blast, possibly contributing to oversize muck and ore dilution. Pillar separation should not be a problem, however, as the majority of pillars are completely isolated from the abutments.

The large muck noted in the muck piles on the backside of some blasted pillars, attributed to short drill holes and/or loose rock, was at a manageable size in all cases.

4. GROUND REACTIONS

It was important to the overall success of the study that ground reactions predicted in the Phase 2 study be verified in the Phase 3 trial by site monitoring. The anticipated ground response based on the Phase 2 analytic study had to be confirmed in the test trial before consideration could be given to the removal of the remaining post-pillars and possibly design modifications.

Roof, wall and pillars were subjected to visual inspections prior to the removal of five pillars in the test stope. Boreholes up to 6 m into the roof were inspected with a Welch Allen fibre optics colour video probe and the images stored on video tape (1).

Ground response to pillar extractions was determined using ground movement monitors (GMM) and CANMET strain rings. They were selected for use in this investigation because of their simplicity, reliability and cost effectiveness.

Ten GMMs were installed in the stope back and three in the pillars to determine relative ground movements. CANMET strain rings were installed in P37-10/2 pillar and both north and south wall abutments to determine stress changes during post-pillar recovery, (see Figure 2). Details of the instrumentation are described in the

Phase 1 Report (1). Ground movements were recorded before, during, and after pillar extractions using dataloggers. Readings were also made manually, particularly with respect to the GMM units before dataloggers were available.

The following is a summary of ground reactions in the vicinity of the pillars removed:

4.1 Roof Reaction

Six GMM units were located in the vicinity of the blasted pillars (see Figure 2). Relative ground movements were determined from reference readings taken on March 3, 1990. The calibration factor for the variable resistor sensors is 190 Ohm/mm. The change in resistance for the five pillar blasts is given in Table 1. It indicates that the roof moved down after the pillars were removed by less than 2 mm which is considered to be insignificant. The GMM units also established that there was no significant increase in movement rate with pillar removed.

Observations of the roof after pillar blasting did not detect signs of deterioration. The roof was very smooth and roof separation or damage was not evident. Both monitoring instrumentation and observations indicate the ground as stable in the present mine geometry.

Table 1 Ground movement monitor reading during pillar removal in Ohms
(* - unstable reading, ** - no reading obtainable), 190Ω = 1 mm

	Sites							
Date	2	3	4	5	6	8	9	Notes
07/01/1991	19348	19744	17274	20210	18851	19149	19395	reading before blast
13/02/1991	19333	19609	17262	20095	18674	*	18742	after P38-10/1 blast
change	-15	-135	-12	-115	23	**	-653	
27/02/1991	19343	19609	17267	20095	18680	18914	**	reading before blast
01/03/1991	19343	19609	17267	20095	18703	18914	**	after P37-11/2 blast
change	0	0	0	0	23	0	**	
05/03/1991	19362	19609	17267	20095	18722	18937	**	reading before blast
07/03/1991	19352	19609	17267	20095	18713	18928	**	after P37-11/1 blast
change	-10	0	0	0	-9	-9	**	
17/03/1991	19352	19609	17267	20095	18713	18928	**	reading before blast
19/03/1991	19342	19609	17267	20095	18707	18923	**	after P37-10/1 blast
change	-10	0	0	0	-6	-5	**	
23/04/1991	19348	19609	17272	20095	18707	**	**	reading before blast
30/04/1991	19343	19609	17248	*	18703	**	**	after P37-10/2 blast
change	-5	0	-24	**	-4	**	**	
05/07/1991	19333	19609	17248	**	18703	**	**	last reading avail.

4.2 Pillar Reaction

CANMET strain monitors were installed in pillar P37-10/2 to determine its deformations in both vertical and horizontal directions using 153 mm diameter borehole. Rings were installed on May 11, 1989. The horizontal strain ring was installed at a depth of 4.40 m from the collar located on the NW pillar side; the calibration factor of the ring was 0.000431 mm/Hz. The vertical ring, installed at a depth of 4.60 m, had a calibration factor of 0.000498 mm/Hz. A summary of the readings obtained from monitoring the rings located in the central section of the sulphide ore pillar is given in Table 2:

Table 2 CANMET strain monitor readings in P37-10/2 sulphide pillar

Date	Horizontal reading changes (Hz)	Vertical reading changes (Hz)
06/02/1990	commencement of readings	
06/06/1990	-24	24
07/03/1991	51	60
19/03/1991	3	0

Negligible borehole deformation occurred as a result of blasting P37-10/1 pillar. Since installation, the CANMET strain monitors have measured increases in vertical and horizontal stresses of 10.53 MPa and 5.80 MPa, respectively. However, the magnitudes of these stresses are not high enough to cause pillar failure.

4.3 Reaction of South Abutment in Dolomite

In the south abutment, CANMET strain monitors were installed in 153 and 75.7 mm diameter holes to monitor reactions in the vertical and horizontal directions. The horizontal gauge was installed in the 153 mm borehole (Site 6"-3) at a depth of 4.40 m from the collar on May 17, 1989. It had a calibration factor of 0.000525 mm/Hz. The vertical gauge was installed in the same hole at a depth of 4.60 m from the collar. The calibration factor for this unit was 0.000476 mm/Hz. Table 3 summarizes the results of readings.

Table 3 CANMET strain monitor readings in the south abutment, 153 mm borehole

153 mm Borehole			
Date	Horizontal reading changes (Hz)	Vertical reading changes (Hz)	Notes
06/02/1990	commencement of readings		
14/02/1991	0	0	reading before blast
01/03/1991	1	2	after P37-11/2 blast
07/06/1991	0	2	

Sensors at site 6"-3 provided very stable data which did not indicate any effect from load redistribution due to pillar recovery.

A horizontal 75.5 mm diameter borehole located about 55 m southeast from Site 6"-3 was fitted with a vertical sensor on December 11, 1990. The strain ring, located at 4.60 m from collar, had a calibration factor of 0.000222 mm/Hz. A horizontal sensor was installed on the same date at 4.25 m from the collar. It had a calibration factor of 0.000240 mm/Hz. A summary of the readings of the units is shown in Table 4.

Table 4 CANMET strain monitor readings in the south abutment, 75.7 mm borehole

75.7 mm Borehole			
Date	Horizontal reading changes (Hz)	Vertical reading changes (Hz)	Notes
14/02/1991	0	0	reading before blast
01/03/1991	5	-4	after P37-11/2 blast
05/03/1991	-4	-4	
07/06/1991	-4	*	* sensor failed

The results indicate that the reactions for both locations in the south abutment are very small and are considered insignificant.

4.4 Reactions of North Abutment in Sulphides

The north abutment is located much closer to the pillar recovery area than the south abutment. To monitor the reaction of the north abutment, two strain monitors were installed on December 11, 1990 in a horizontal drill hole with a diameter of 75.7 mm. The vertical gauge, installed at a depth of 4.60 m from the collar, had a calibration factor of 0.000136 mm/Hz. The horizontal gauge, installed at a depth of 4.25 m, had a calibration factor of 0.000142 mm/Hz. The results are summarized in Table 5:

Table 5 Reactions of CANMET strain monitors in north abutment, 75.7 mm borehole

75.7 mm Borehole			
Date	Horizontal reading change (Hz)	Vertical reading change (Hz)	Notes
20/02/1991	0	0	reading before blast
01/03/1991	1	25	after P37-11/2 blast
05/03/1991	0	0	reading before blast
06/03/1991	-2	6	after P37-11/1 blast
17/03/1991	0	0	reading before blast
19/03/1991	9	4	after P37-10/1 blast
23/04/1991	0	0	reading before blast
07/06/1991	67	80	after P37-10/2 blast
05/07/1991	24	40	no blast activity

Summarizing, ground reaction due to removal of the five pillars caused the rings to deform 0.004 mm in the vertical direction and 0.001 mm in the horizontal direction. The abutment stress changes, calculated on the bases of an elastic modulus of 29 GPa and a Poisson's ratio of 0.25, are 1.98 MPa in the vertical direction and 1.04 MPa in the horizontal direction.

The stress changes are so small as to be at the limit of the monitoring systems sensors. The small stress changes are consistent with the lack of observation of severe ground damage accompanying the blasting and removal of the five pillars. Ground conditions in the present mining geometry are considered to be stable.

4.5 Comparison of Numerical Models with Ground Monitoring Results

Monitoring data from the north wall abutment was compared with data from computer simulations using plane strain state modelling. It was considered that the north wall abutment is best simulated by plane strain state conditions. The relevant vertical and horizontal stresses determined from the CANMET strain rings and computer models were compared as shown in Table 6 below:

Table 6 Comparison of Stresses in the north wall abutment

North Wall Abutment Stresses			
Stress (MPa)	Monitoring - CANMET strain ring	Numerical model	Discrepancy (%)
Vertical Stress	1.98	1.99	0.5
Horizontal Stress	1.04	0.44	58.0

Table 6 indicates that the magnitude of the vertical stress obtained from field measurement is in good agreement with that predicted by the model. The magnitude of the horizontal stress is not in good agreement with model prediction.

In order to close the gap between the model and monitoring results, back analysis was carried out to verify input parameters. In this case study, a series of computer simulations were executed by varying horizontal stress component parameters. Back analysis established that input values for the horizontal principal stress components should be 3 and 0.85 times the vertical stress component rather than 3 and 0.7 times, the values originally used.

Using the new input values established for horizontal principal stress components, a series of computer simulations were made to verify ground stress distributions and pillar reactions. Table 7 provides a comparison of numerical model established stresses and monitored stresses in P37-10/2 pillar. It can be seen that the model and monitoring results are in good agreement.

Table 7 Comparison of Stresses in the P37-10/2 pillar

P37-10/2 Pillar Stresses			
Stress (MPa)	Monitoring - CANMET strain ring	Numerical model	Discrepancy (%)
Vertical Stress	10.53	10.62	0.85
Horizontal Stress	5.80	5.52	4.83

The total vertical displacement in the roof following the mining of all pillars across the stope using the new data was compared with data generated from the Phase

2 study, (see Figure 4). The Phase 3 roof deformations are less than those obtained in the Phase 2 analysis. This implies, as expected, that higher in-situ horizontal stresses are beneficial to roof stability. The induced vertical and horizontal stresses in the wall abutments are different, in the north abutment 2.45 MPa and 1.13 MPa, and in the south abutment 5.44 MPa and 2.56 MPa, respectively. These stresses are not high enough to cause compressive failure of the abutments but they will be useful for future comparison with monitoring results.

Figures 5 to 7 show the relaxation zones developed using the new input parameters. Figures 8 to 10 show the relaxation zones developed in the Phase 2 analyses. It can be seen that the relaxation and potential failure zones are reduced significantly due to higher horizontal stress components. The results from the Phase 2 study can be viewed as conservative.

To date, six months after all five pillars were removed, the ground around the stope still shows no sign of deterioration and is considered to be stable as predicted.

5. CONCLUSIONS AND OBSERVATIONS

Based on the results of this investigation, the following main conclusions and observations are made:

1. All five post-pillars in the test stope were successfully recovered. Analysis of data from monitoring instrumentation and underground observations indicates the present mine geometry is stable as predicted. The results are very encouraging and support the feasibility of extracting all the remaining post-pillars.

2. Drilling and blasting trials in the test stope with post-pillars have indicated that 63.5 mm holes and a 1.4×1.4 m pattern seem the most cost effective for blasting the remaining post-pillars. Blasting should be initiated with the simultaneous blasting of the three bottom rows of horizontal holes followed by the sequential detonation by rows toward the back with single delays. This will achieve good fragmentation and limited muck throw. More work needs to be done on an on going basis to improve drilling pattern and blasting.

3. Pillar ore contacts with dolomite should be carefully blasted, as in the case of the test stope, in order to minimize roof damage and muck size.

4. The pillar roofs were smoothly blasted. No significant roof deformations was detected by ground movement monitors.

5. Back analysis indicates that the horizontal principal stress components should be 3 and 0.85 times, the vertical stress component respectively. Higher in-situ horizontal stresses are beneficial to roof stability

6. The north wall abutment and P37-10/2 pillar stresses determined with CANMET strain rings are in good agreement with numerical model stresses.

7. Modelling indicated that when all pillars across the stope were mined, the induced vertical and horizontal stresses in the two abutments would be different: in the north abutment 2.45 MPa and 1.13 MPa, and in the south abutment 5.44 MPa and 2.56 MPa, respectively. This difference can be used in the interpretation of future monitoring results.

8. The Phase 2 study provided conservative data for consideration in planning the extraction of the remaining post-pillars.

9. Ground monitoring programs should be maintained and implemented, if the decision is made to proceed with the mining of post-pillars, especially roof deformation and pillar stress monitoring to meet possible design modification and ground control requirements.

10. During pillar extraction ground conditions should be regularly observed and the information fed back to CANMET. This will permit continued development of a ground control expert system and if necessary, permit additional simulations for use by Nanisivik mine in undertaking design modifications.

6. ACKNOWLEDGEMENTS

Thanks are due to Messrs. W. McNeil, Mine Manager; J.C. McConnell, Mine Superintendent; R. Marion, Chief Engineer; and A. Boudreault, Mine Engineering staff, as well as P. Hansman, former Chief Engineer for their helpful cooperation in this project. Mr. M. Irving, MDA-Coordinator NWT is also to be thanked for his valuable suggestions.

7. REFERENCES

1. B. Arjang and G. Herget; "Post pillar recovery strategies at Nanisivik Mine, Phase 1 : Ground control instrumentation and stress determination"; Division report, MRL 89-147(TR); CANMET project No. 144610-01-4; November 1989.

2. S. Vongpaisal, J.E. Udd and G.E. Larocque; "Post pillar recovery strategies at Nanisivik Mine, Phase 2 : Ground stability evaluation", Division report, MRL 90-27(TR); CANMET project No. 144610-01-4; April 1990.

3. F. Bailey; "Pillar recovery project - results of test stope mining", Nanisivik Mines Limited; August 26, 1991.

APPENDIX A

Figures

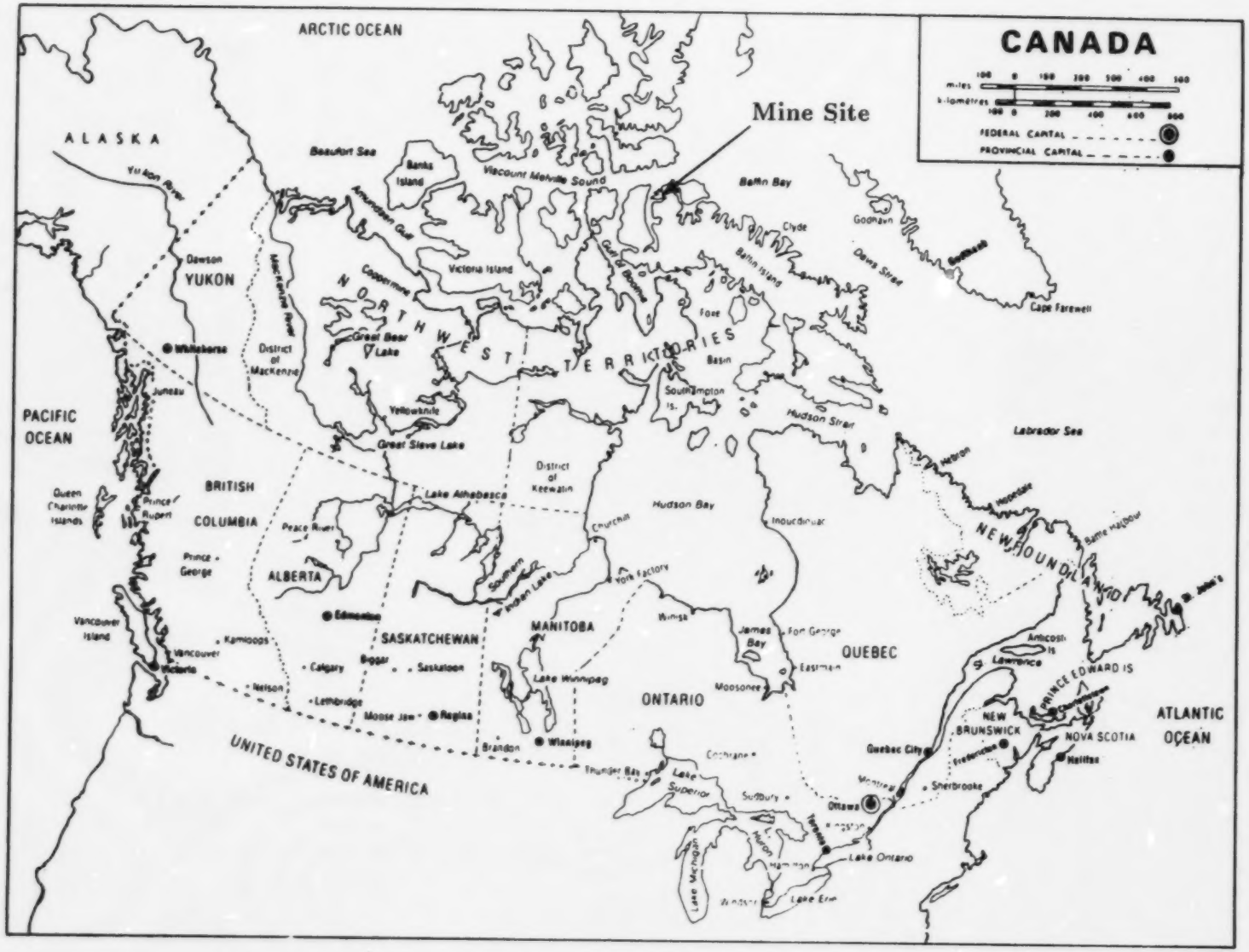

Fig. 1 - Location of Nanisivik Mine, Baffin Island, N.W.T.

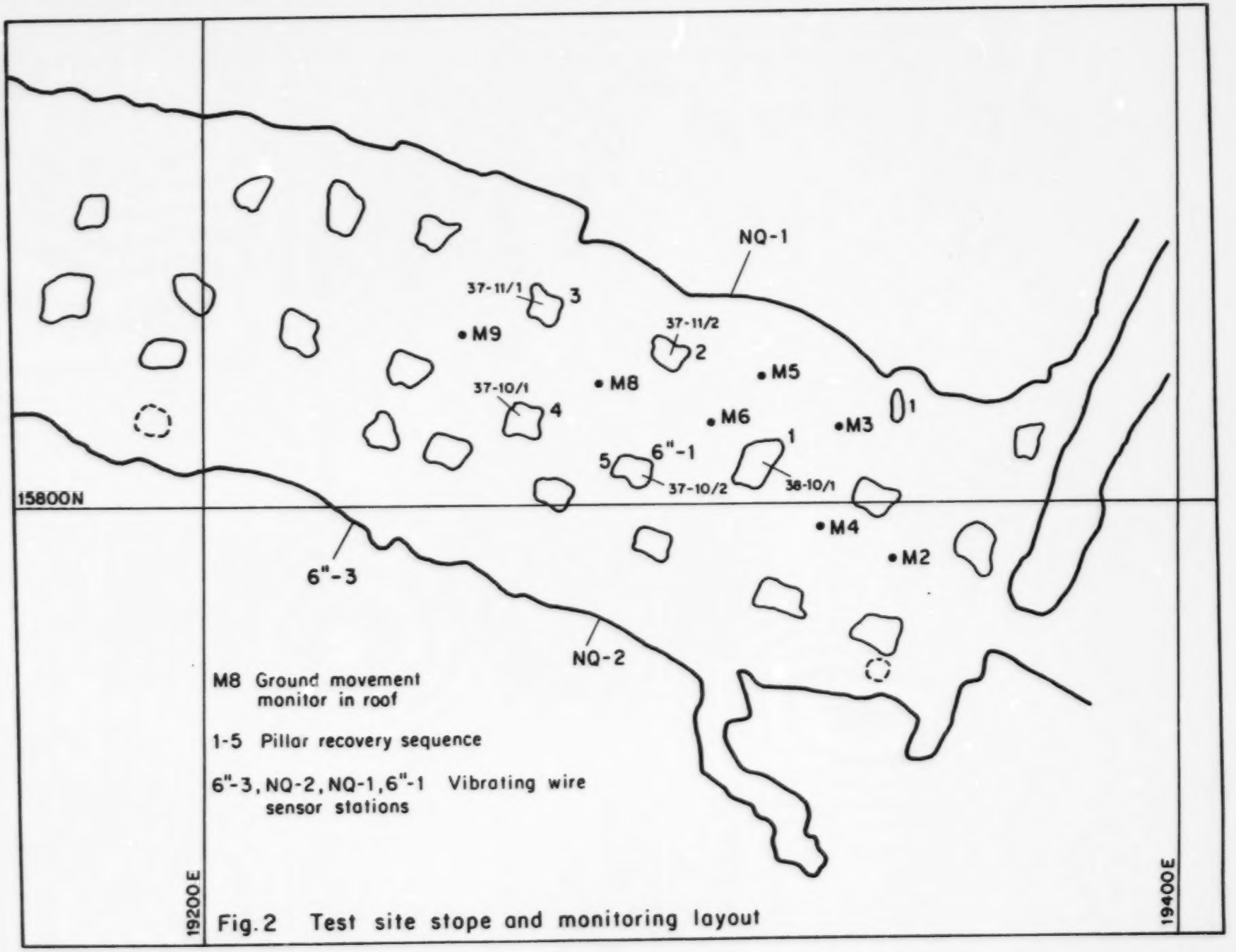

Fig. 2 Test site stope and monitoring layout

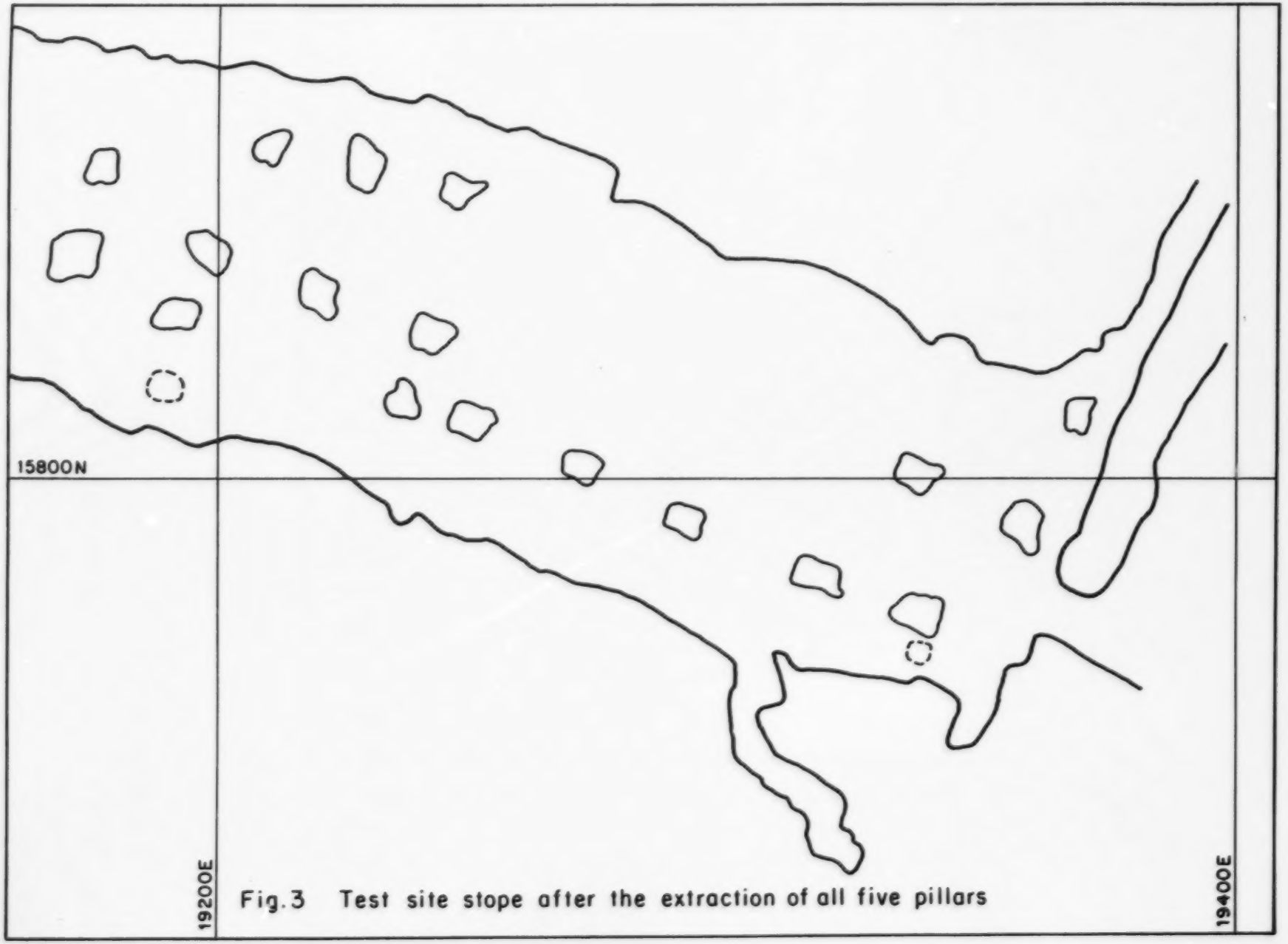

Fig.3 Test site stope after the extraction of all five pillars

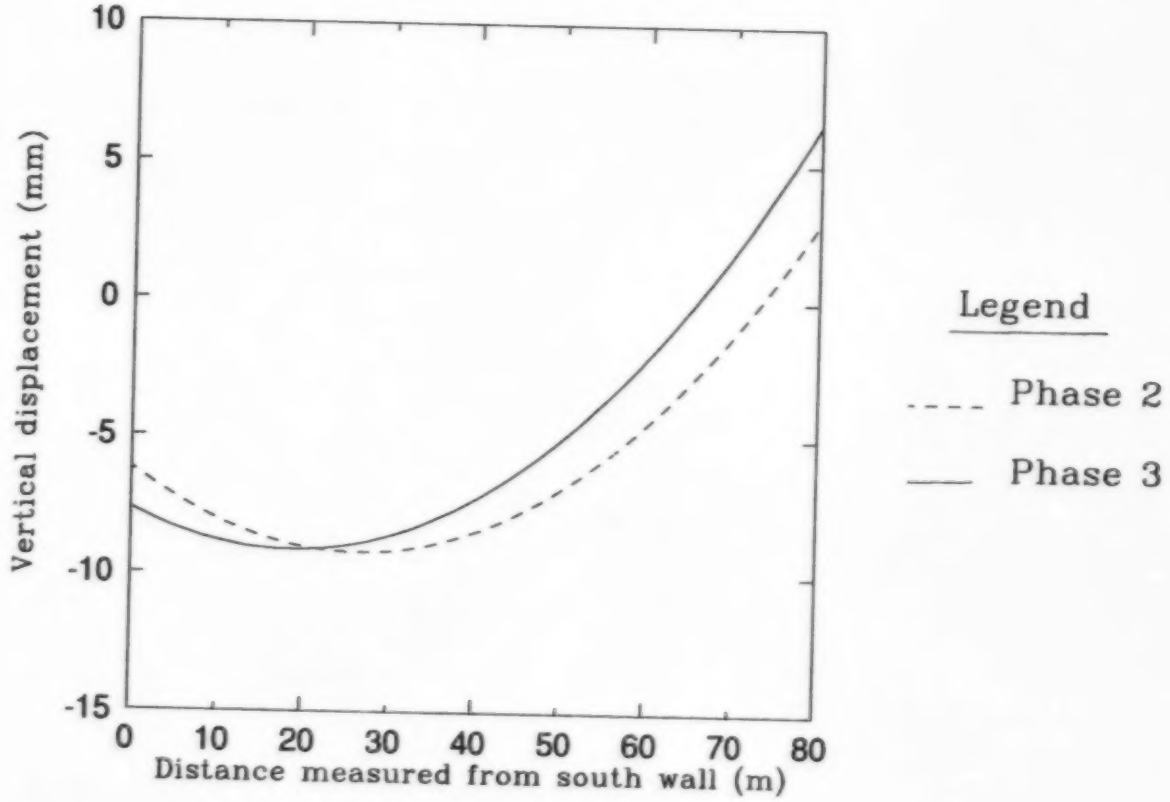

Fig. 4 – Excavation Displacements at Stope Roof, Model 2, Section 19250E, P_1, P_2, P_3, Mined

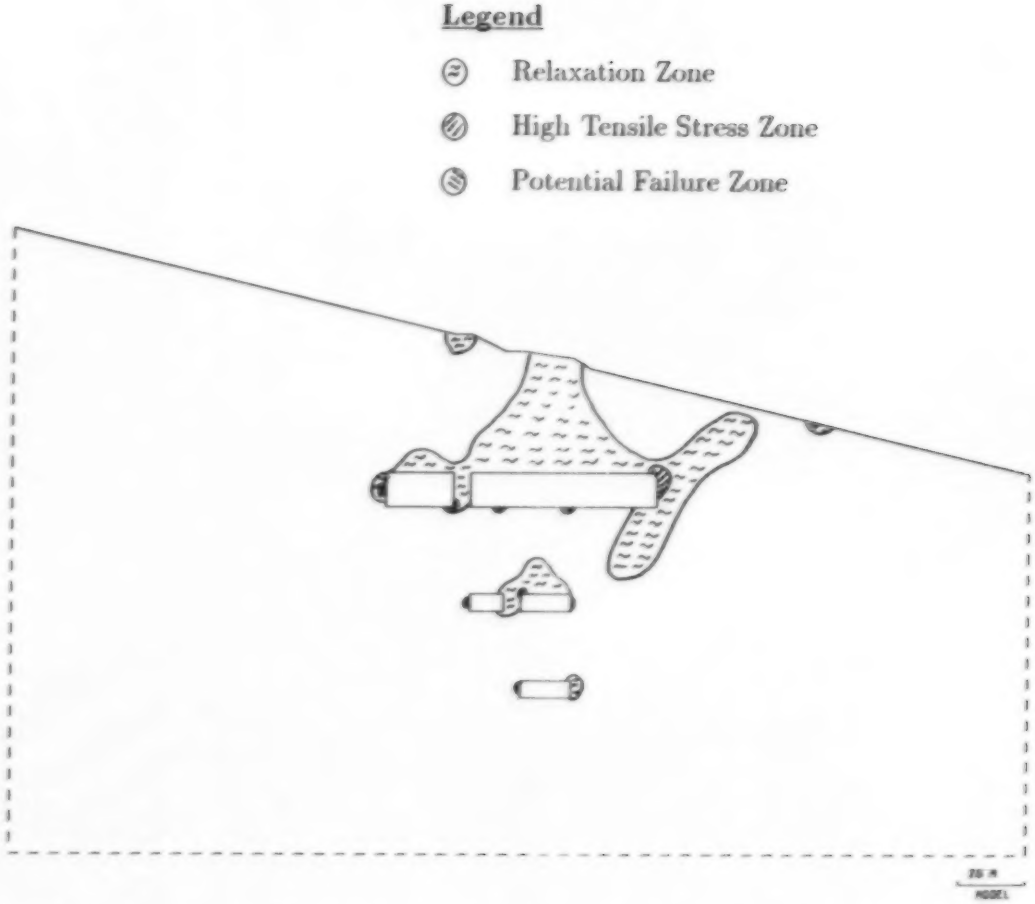

Fig. 5 - Relaxation Zone, Model 2, Section 19250E, P2,P3 Mined, Phase 3

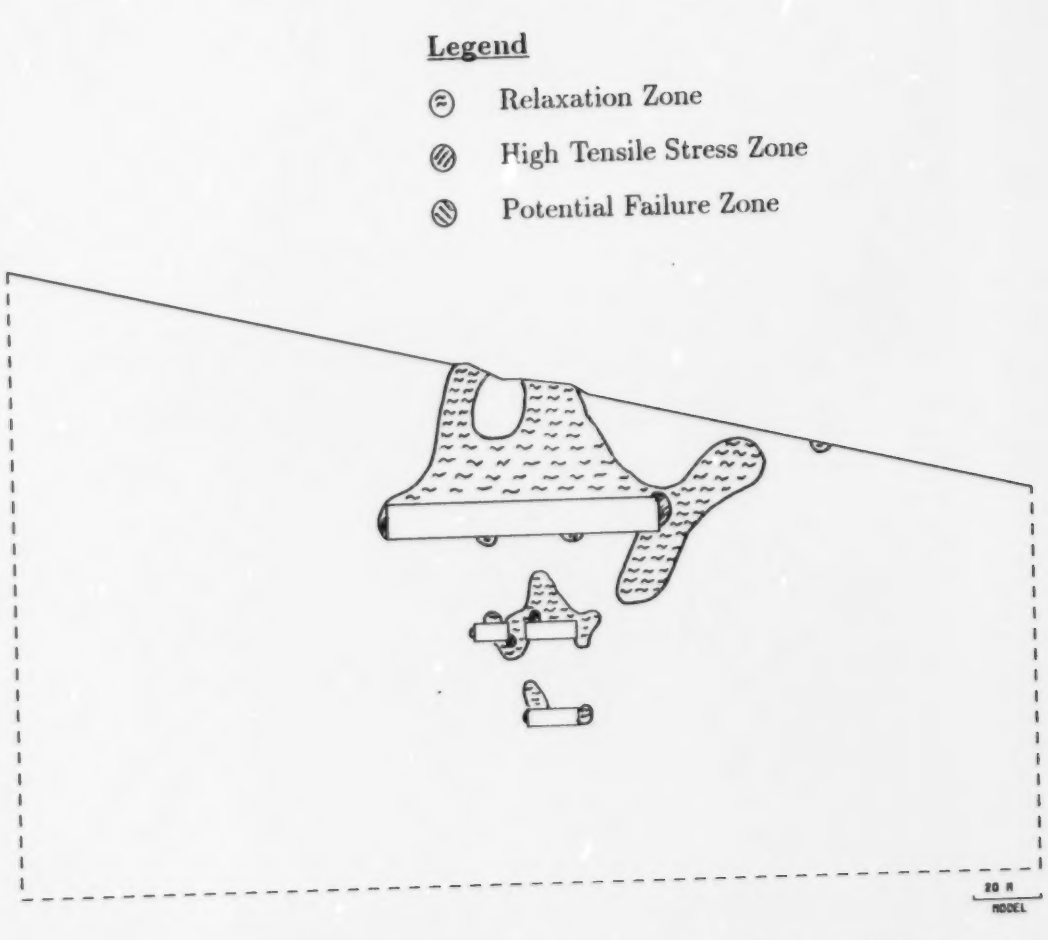

Fig. 6 - Relaxation Zone, Model 2, Section 19250E, P1,P2,P3 Mined, Phase 3

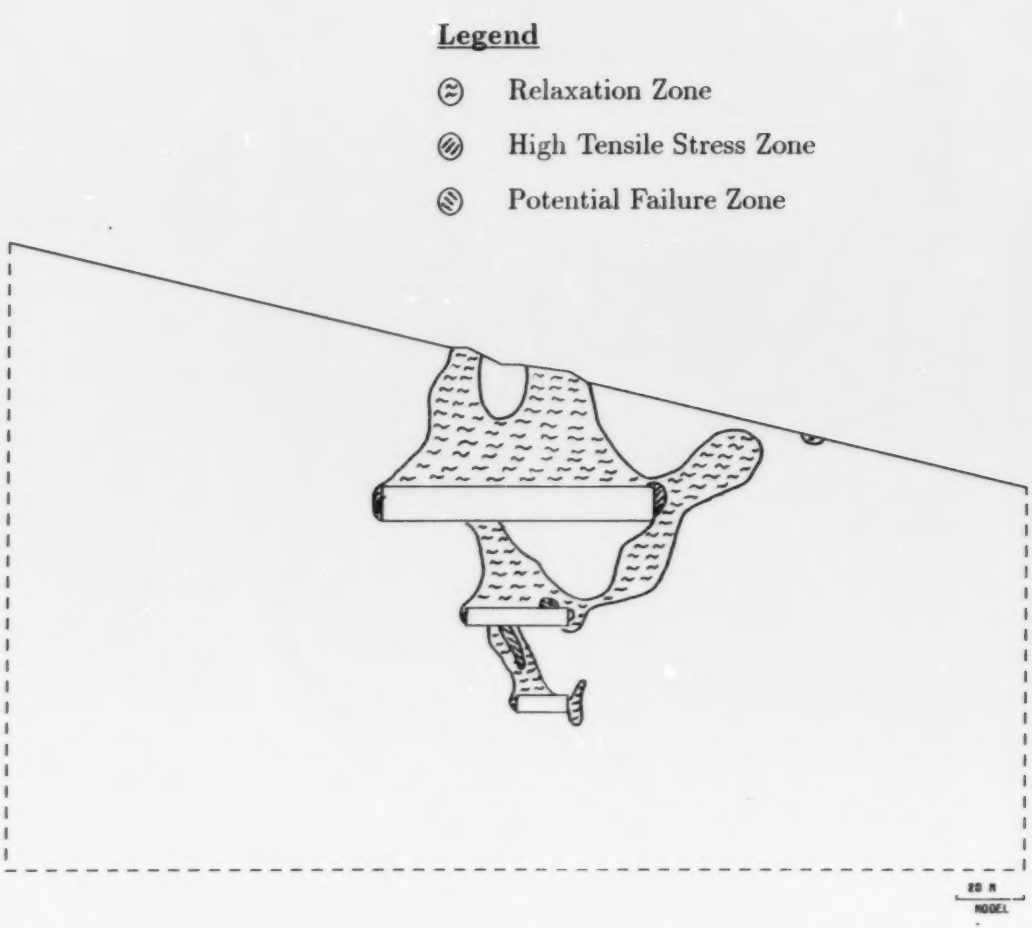

Fig. 7 - Relaxation Zone, Model 2, Section 19250E, P1,P2,P3,P4 Mined, Phase 3

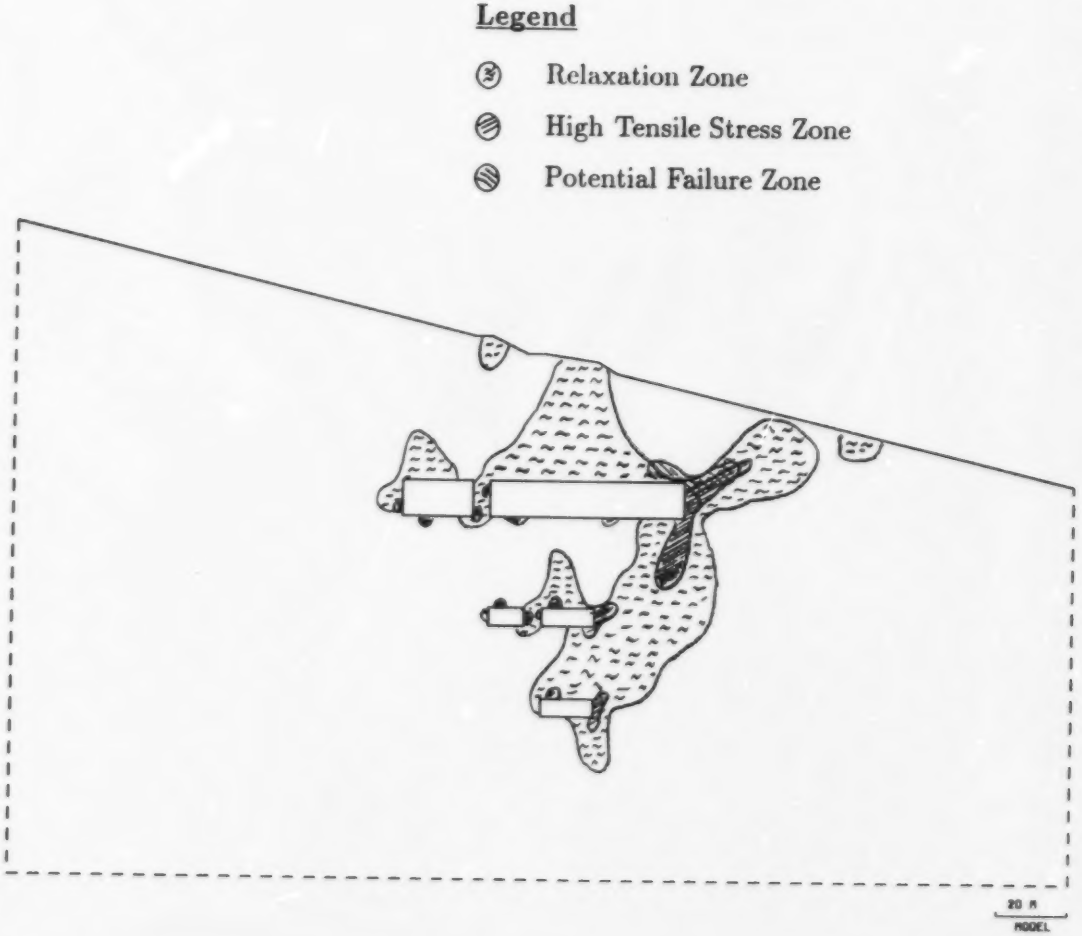

Fig. 8 - Relaxation Zones, Model 2, Section 19250E, P2,P3, Mined, Phase 2

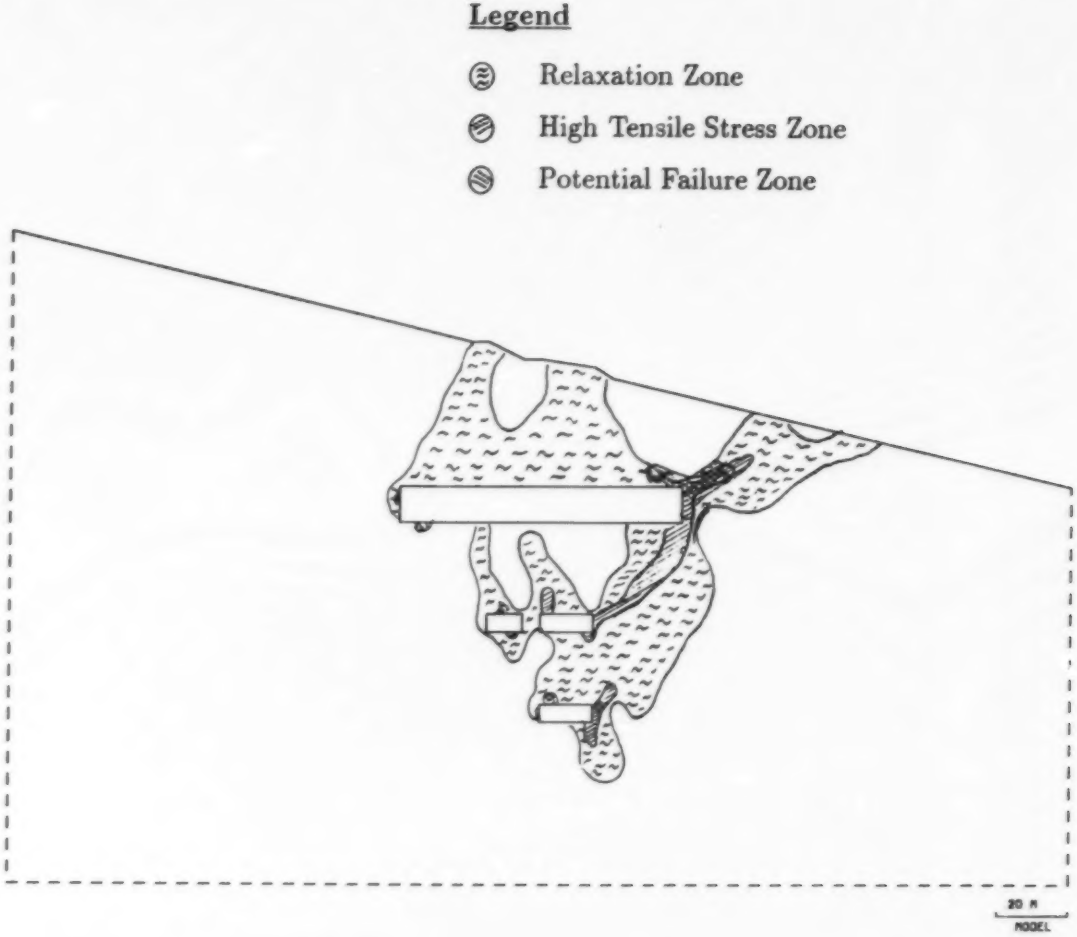

Fig. 9 - Relaxation Zones, Model 2, Section 19250E, P1,P2,P3, Mined, Phase 2

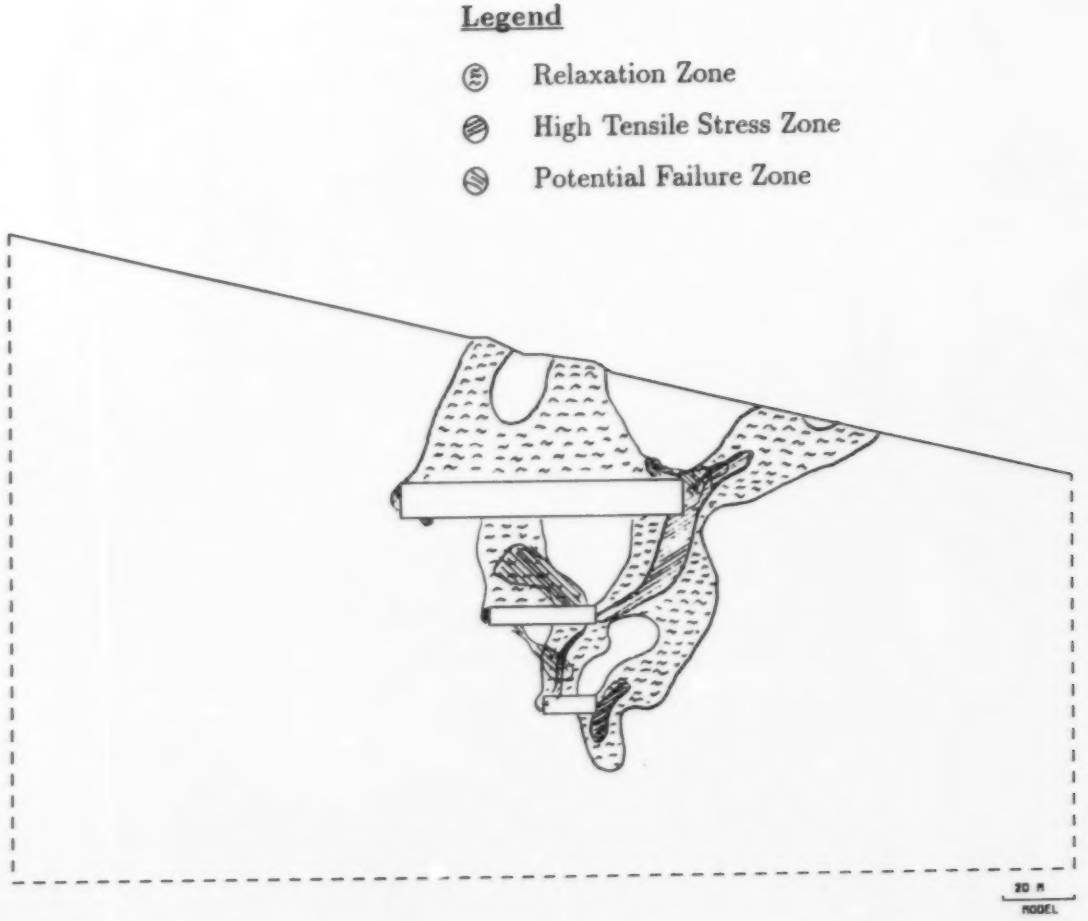

Fig. 10 - Relaxation Zones, Model 2, Section 19250E, P1,P2,P3,P4 Mined, Phase 2